SWIRL NOZZLE AND METHOD OF MAKING SAME

CROSS-REFERENCE TO RELATED APPLICATION

The present application claims the benefit of U.S. Provisional Application Serial No. 60/409,527, filed on September 9, 2002, entitled "Swirl Nozzle And Method Of Making Same", and similarly titled U.S. Patent Application Serial No. 10/272,241, filed October 16, 2002, each of which is hereby expressly incorporated by reference as part of the present disclosure.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The subject disclosure relates to fine spray nozzles, and more particularly to nozzles which create a vortex to form a fine spray.

2. Background of the Related Art

Traditionally, fine spray nozzles utilize either an impingement or an air-atomizing design to produce small droplets. Impingement is simply directing the flow of fluid through an orifice onto a pin to generate the spray. A primary disadvantage of impingement designs is that the target pin is difficult to align and can easily become damaged or misaligned resulting in poor performance. Moreover, a target pin may become dislodged and create damage downstream. Another drawback associated with impingement nozzles is that the orifice/pin feature tends to wear over the life of the nozzle which, in turn, may adversely affect spray pattern and drop size over the life of the nozzle. Air-atomizing designs are another well-known type of design which utilizes a source of pressurized air to atomize the fluid. A primary disadvantage of the air-atomizing designs is the increased expense of providing and maintaining the source of pressurized air.

In view of the above, several nozzles which utilize a swirling flow have been developed as alternatives. Swirling flow nozzles convert the head pressure of the fluid into kinetic energy within a swirl chamber. The swirling action causes the liquid to form into a thin, conical sheet that disintegrates into droplets under the action of aerodynamic and surface tension forces. Exemplary swirl flow nozzles are shown in U.S. Patent Nos. 3,771,728; 3,532,271; and 6,186,417. Heretofore, several factors have limited the applicability of swirl flow nozzles, including: poor tolerance when machining the materials from which the nozzles are made; the spray patternation quality deteriorates as the size of the swirl chamber decreases; clogging due to smaller dimensions; and small parts become difficult to handle and assemble.

There is a need, therefore, for an improved small spray nozzle that overcomes one or more of the above-described drawbacks of the related art.

SUMMARY OF THE INVENTION

The present invention is directed to a spray nozzle comprising a body defining an inlet aperture and an outlet aperture. An orifice disk of the spray nozzle is receivable within the body adjacent to the outlet opening and includes a sheet material substrate defining a first surface formed on one side of the substrate, a second surface formed on an opposite side of the substrate relative to the first surface, a side surface extending between the first and second surfaces and defining a peripheral edge of the orifice disk, and a spray orifice extending through a first region of the substrate spaced inwardly relative to the peripheral edge. A swirl disk of the nozzle is receivable within the body adjacent to the orifice disk and includes a sheet material substrate defining a first surface formed on one side of the substrate, a second surface formed on an opposite side of the substrate relative to the first surface, and a side surface extending between the first and second surfaces and defining a peripheral edge of the swirl disk. A swirl chamber of the swirl disk is defined by a first aperture extending through a first region of the substrate spaced inwardly relative to the peripheral edge, and a swirl inlet is defined by a second aperture formed through a second region of the substrate extending between the swirl chamber and peripheral edge. A plug of the nozzle is receivable within the body adjacent to the swirl disk for retaining the swirl disk and orifice disk within the body. The plug defines a fluid flow path coupled in fluid communication between the inlet of the body and the inlet of the swirl disk for directing fluid flowing through the inlet of the body into the swirl chamber and, in turn, imparting a swirling flow to the fluid prior to discharging the fluid through the spray orifice in a spray pattern emanating therefrom.

The present invention also is directed to a method of forming a swirl disk of a spray nozzle, wherein the method includes the steps of: (1) providing a sheet of material for forming the swirl disk therefrom; and (2) forming at least one swirl disk from the sheet of material by (i) removing material about a peripheral portion of the swirl disk and, in turn, forming a peripheral edge of the swirl disk, (ii) removing material from at least one first region of the swirl disk spaced inwardly relative to the peripheral edge of the swirl disk and, in turn, forming a first aperture extending through the first region and defining a swirl chamber, and (iii) removing material from at least one second region of the swirl disk extending between the swirl chamber and peripheral edge of the swirl disk and, in turn, forming a second aperture extending through the second region and defining a flow inlet to the swirl chamber.

In a currently preferred embodiment of the present invention, the method further comprises the step of providing an orifice disk for use with the swirl disk of the spray nozzle. The step of providing the orifice disk includes the steps of: (1) providing a sheet of material for forming the orifice disk therefrom; and (2) forming at least one orifice disk from the sheet of material by (i) removing material about a peripheral portion of the orifice disk and, in turn, forming a peripheral edge of the orifice disk, and (ii) removing material from at least one first region of the orifice disk spaced inwardly relative to the peripheral edge of the orifice disk and, in turn, forming a first aperture extending through the first region and defining a spray orifice.

In one embodiment of the present invention, each step of removing sheet material is performed by etching. In addition, the first and second surfaces of the swirl disk are preferably symmetrical about a plane perpendicular to the axis of the spray nozzle. Also in a currently preferred embodiment of the present invention, the first and second surfaces of the swirl disk are substantially planar throughout. In yet another currently preferred embodiment of the present invention, the first and second surfaces of the swirl disk are substantially identical.

One advantage of the present invention is that the nozzles utilize a vortex to create a fine mist, thereby enabling a reduction in manufacturing complexity and maintenance costs while permitting increased reliability and performance in comparison to prior art impingement and/or air-atomizing nozzles.

Another advantage of a currently preferred embodiment of the present invention is that it permits the exchange of variously configured swirl and orifice disks to fine tune nozzle performance for a specific application.

It should be appreciated that the present invention can be implemented and utilized in numerous ways, including without limitation as a process, an apparatus, a system, a device (including, for example, a nozzle assembly, a swirl disk and an orifice disk) and a method for applications now known and later developed. These and other unique features of the invention disclosed herein will become more readily apparent from the following detailed description of preferred embodiments, claims and the accompanying drawings

BRIEF DESCRIPTION OF THE DRAWINGS

So that those having ordinary skill in the art to which the disclosed invention appertains will more readily understand how to make and use the same, reference may be had to the drawings wherein:

Figure 1 is a perspective exploded view of a first nozzle embodying the present invention;

Figure 2A is an enlarged partial, cross-sectional view of a body for the nozzle of Figure 1;

Figure 2B is a cross-sectional view of the body for the nozzle of Figure 1;

Figure 2C is an end view of the body for the nozzle of Figure 1;

Figure 3A is a front view of an orifice disk for the nozzle of Figure 1;

Figure 3B is a side view of the orifice disk for the nozzle of Figure 1;

Figure 4A is a front view of a swirl disk for the nozzle of Figure 1;

Figure 4B is a side view of the swirl disk for the nozzle of Figure 1;

Figure 5A is a side view of a plug for the nozzle of Figure 1;

Figure 5B is a cross-sectional view of the plug for the nozzle of Figure 1;

Figure 5C is an end view of the plug for the nozzle of Figure 1;

Figure 5D is another end view of the plug for the nozzle of Figure 1;

Figure 6A is a side view of the nozzle of Figure 1 in an assembled state;

Figure 6B is an end view of the nozzle of Figure 6A;

Figure 6C is a cross-sectional view of the nozzle of Figure 6A;

Figure 6D is an enlarged partial cross-sectional view of the nozzle of Figure 6C;

Figure 7 is a perspective cross-sectional view of the nozzle of Figure 6A;

Figure 8 is a perspective exploded view of another nozzle embodying the present invention;

Figure 9A is an end view of a body for the nozzle of Figure 8;

Figure 9B is a cross-sectional view of the body for the nozzle of Figure 8;

Figure 10A is a front view of an orifice disk for the nozzle of Figure 8;

Figure 10B is a side view of the orifice disk for the nozzle of Figure 8;

Figure 11A is a front view of a swirl disk for the nozzle of Figure 8;

Figure 11B is a side view of the swirl disk for the nozzle of Figure 8;

Figure 12A is an end view of the plug for the nozzle of Figure 8;

Figure 12B is a side view of the plug for the nozzle of Figure 8;

Figure 12C is another side view of a plug for the nozzle of Figure 8;

Figure 13A is an end view of the nozzle of Figure 8 in an assembled state;

Figure 13B is a cross-sectional view of the nozzle of Figure 13A;

Figure 13C is another end view of the nozzle of Figure 13A;

Figure 13D is an enlarged partial, cross-sectional view of the nozzle of Figure 13A;

Figure 13E is another enlarged partial, cross-sectional view of the nozzle of Figure 13A;

Figure 14 is a front view of another embodiment of a swirl disk of the present invention;

Figure 15 is a front view of another embodiment of an orifice disk of the present invention for use with the swirl disk of Figure 14;

Figure 16 is a perspective view of another nozzle embodying the present wherein the body of the nozzle is formed by metal injection molding ("MIM") and the swirl chamber and spray orifice are formed integral with the body instead of being formed by separate disks as in the embodiments described above;

Figure 17A is an enlarged partial, cross-sectional view of the body of Figure 16;

Figure 17B is a cross-sectional view of the body of Figure 16;

Figure 17C is an end view of the body of Figure 16;

Figure 17D is another end view of the body of Figure 16; and

Figure 17E is an enlarged partial end view of the body of Figure 16.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention overcomes many of the prior art problems associated with spray nozzles. The advantages, and other features of the nozzles disclosed herein, will become more readily apparent to those having ordinary skill in the art from the following detailed description of certain preferred embodiments taken in conjunction with the drawings which set forth representative embodiments of the present invention and wherein like reference numerals identify similar structural elements.

Referring to Figure 1, an exploded view of a nozzle referred to generally by reference numeral 10 is shown. The nozzle 10 has a body 12 for engaging a pipe or other structure (not shown) by a threaded end 14. The body 12 defines an outlet 16 (see Figures 2A-C) for discharging the liquid. An inlet chamber 18 is formed in the body 12 for receiving an orifice disk 20 and a swirl disk 22. A plug 30 retains the disks 20, 22 in place. As

described further below, the orifice and swirl disks 20, 22 are each formed of a sheet material, such as stainless steel or other metal, by an etching or other feasible technique or process. The term sheet material or sheet-like material is used herein to mean a piece of any material that is broad in extent and comparatively thin. In addition, the term disk is used herein to mean a thin, substantially flat article that may define planar surfaces, but also may define depressed or elevated portions on or within its surfaces.

The nozzle 10 is scalable to a number of different flow rates, droplet sizes and spray angles. For example, the nozzle 10 may be configured to function under very low flow rates (less than about 0.05 gpm) and still produce a population of droplets with a Sauter Mean Diameter on the order of about 20 microns at pressures of about 1000 psi. As a result, for systems in which the nozzle of the present invention is installed, the required flow of liquid can be achieved with reduced initial costs for pumping equipment and/or lower operating costs in comparison to such systems employing prior art spray nozzles. Exemplary pipe sizes are 1/8" and 1/4" pipes. Exemplary applications for the nozzle 10 include, without limitation, turbine cooling, fire misting, livestock cooling, gas quenching, humidification, evaporative cooling, coating, spray drying of low abrasion liquids, area misting, cooling of castings, direct contact cooling, and the like.

Referring to Figures 3A and 3B, the orifice disk 20 has a central aperture 24 and is placed in the bottom of the inlet chamber 18 so that the central aperture 24 is adjacent to and axially aligned with the outlet 16 of the body 12. Referring to Figures 4A and 4B, the swirl disk 22 has a substantially central hollow 28 defining a swirl chamber for forming a vortex of the liquid therein. The swirl disk 22 is placed adjacent to the orifice disk 20 in the chamber 18 so that the central hollow 28 is adjacent to and axially aligned with the central aperture 24. The disks 20, 22 are round which creates a self-centering effect within the chamber 18 of the body 12. The disks 20, 22 are also symmetrical (e.g., each disk is symmetrical about a respective plane approximately perpendicular to the axis of the nozzle) so that the nozzle 10 can be easily assembled and reversal will not impact performance. Therefore, the nozzles of the present invention not only avoid the need for a pin or a source of pressurized air as required by prior art impingement and air-atomizing nozzles, but the nozzles of the present invention further avoid the difficulties of assembling and/or aligning individual parts that are associated with certain prior art spray nozzles. Although the currently preferred embodiments of the swirl and orifice disks define circular peripheries, the peripheries of these parts may take any of numerous different shapes that may be desired or otherwise required for different applications.

For example, the swirl and/or orifice disks may each define a rectangular, oval, or other irregular-shaped periphery.

The swirl disk 22 also forms an inlet 27 in fluid communication with the central hollow 28 for channeling fluid thereto. The inlet 27 expands gradually from a throat 26 at the central aperture towards the periphery of the swirl disk 22. The throat 26 is determined at the point where the straight portions 25 of the inlet 27 become arcuate. The swirl disk start radius 29 is the minimum radius of the central hollow or swirl chamber 28 of the swirl disk 22. Among other parameters, varying the throat ratio, which is the ratio of the throat 26 to the swirl start radius 29, will vary the shape of the vortex formed within the central hollow 28. Preferably, the throat ratio is within the range of about 3:5 to about 11:10.

Referring to Figures 5A-D, the plug 30 has an intermediate portion 32 for threadably engaging the inlet chamber 18 to retain the disks 20, 22 in place. Each end of the plug 30 is relatively narrower than the intermediate portion 32. As a result, when the plug 30 is inserted in the body 12 an annulus area 34 (see Figure 6D) is formed between the plug 30 and body 12. The annulus area 34 is in fluid communication with the inlet 27 of the swirl disk 22 (Figure 4A). The plug 30 has an internal bore 36 for conducting the fluid into the annulus area 34. A set of four exit orifices 38 are substantially equally spaced about the circumference of the plug 30 at the bottom of the internal bore 36 to allow the fluid to pass from the internal bore 36 to the annulus area 34. A pair of diametrically opposed, axially elongated slots 39 are formed in the end of the plug 30 opposite the exit orifices 38 for gripping by a tool, pick and place robot, or other devices for assembling the plug 30 to the body 12. As may be recognized by those of ordinary skill in the pertinent art based on the teachings herein, the plug may define any number of exit orifices, and the exit orifices may take any of numerous different shapes and/or may be located in any of numerous different locations as desired or otherwise as might be required by a particular application. Similarly, the gripping surface(s) defined by the slots 39 may take any of numerous different shapes and/or configurations for purposes of performing the functions of the slots as described herein.

In the illustrated embodiment of the present invention, the orifice disk 20 and swirl disk 22 are manufactured using a photochemical etching process of a type known to those of ordinary skill in the pertinent art that results in very thin, tight tolerance components preferably formed of stainless steel. One advantage of the photochemical machining process is that it allows the swirl and orifice disks to be etched from sheet material substrates in a manner that obtains sufficiently tight tolerances to produce extremely small droplet sizes that could not

be achieved with certain prior art single fluid whirl nozzles (e.g., droplets with a Sauter Mean Diameter on the order of about 20 microns at about 1000 psi and at flow rates of less than or equal to about 0.05 gpm). Yet another advantage is that the photochemical machining process is a relatively efficient and low-cost method for producing large volumes of relatively tight tolerance components, such as the swirl and orifice disks. Exemplary etching techniques are shown in U.S. Patent No. 5,740,967 to Simmons et al. and U.S. Patent No. 5,951,882 to Simmons et al., each of which is incorporated herein by reference. It is also envisioned that the disks 20, 22 can be fabricated by any of numerous other techniques or processes that are currently or later become known, including metal injection molding, laser cutting, fine stamping, or a combination of any of numerous different processes and/or manufacturing techniques that are currently, or later become known, for manufacturing swirl and/or orifice disks of the type disclosed herein. For example, in one currently preferred embodiment of the present invention, the central aperture 24 of the orifice disk is formed by drilling. In this embodiment, the orifice disk aperture is formed by several drill passes including, e.g., a first pass of a drill to form a relatively rough aperture, and a second pass of a drill to remove any burrs and otherwise clean the periphery of the aperture. In addition, or in lieu of several drill passes, the drilled aperture can be cleaned by lapping or rubbing with or otherwise applying thereto an emery cloth or other device for removing burrs or otherwise cleaning metal surfaces. As may be recognized by those of ordinary skill in the pertinent art based on the teachings herein, for most, if not all applications, it is important that the periphery of the orifice disk aperture be burr free and otherwise define a substantially uniform, smooth and clean surface in order to obtain the desired flow characteristics. In addition, as also may be recognized by those of ordinary skill in the pertinent art based on the teachings herein, although the orifice and swirl disks 20 and 22, respectively, are etched from stainless steel sheets, these disks may be formed from any of numerous other types of metals or other materials that are currently or later become known for performing the functions of the respective disk, and/or as may be required by a particular application or as may be permitted by a particular manufacturing technique or process.

In one embodiment of the present invention, the thickness of the orifice disk is within the range of about 0.005 through about 0.02 inches, and in one example, the thickness of the orifice disk is about 0.005 inches. Also in this embodiment, the swirl disk defines a thickness within the range of about 0.005 through about 0.02 inches, and in one example, the thickness of the swirl disk is about 0.005 inches. In another embodiment of the present

invention, the thickness of the orifice disk is within the range of about 0.005 through about 0.03 inches, more preferably is within the range of about 0.015 through about 0.025 inches, and in one example is about 0.02 inches. In this example, the thicker orifice disk (0.02 inches, as opposed 0.005 inches in the example above) facilitates in preventing undesirable skewing of the spray pattern. Also in this embodiment, the swirl disk defines a thickness within the range of about 0.003 inches through about 0.03 inches, and more preferably, within the range of about 0.005 inches through about 0.015 inches. In one example, the thickness of the swirl disk is about 0.005 inches. Also in a currently preferred embodiment of the present invention, the swirl disk defines a diameter (or maximum width if non-circular) of at least about 0.1 inches. As indicated above, the thickness of the orifice disk can affect the spray pattern and/or other characteristics of the nozzle. Frequently, it is important to evaluate the thickness of the orifice disk ("L") in the context of the diameter of the orifice disk aperture ("D"). In the exemplary embodiment above, the thickness "L" of the orifice disk is about 0.02 inches, the diameter "D" is about 0.005 inches, and therefore L/D is about 4. In currently preferred embodiments of the present invention, the diameter D of the orifice disk aperture is within the range of about 0.005 inches through about 0.03 inches. Also in such currently preferred embodiments of the present invention, the L/D ratio is preferably within the range of about 0.16 through about 6.

Referring to Figures 6A-D and 7, to assemble the nozzle 10, the orifice disk 20 is placed in the bottom of the inlet chamber 18. Similarly, the swirl disk 22 is placed directly adjacent to the orifice disk 20. In a currently preferred embodiment, the inner diameter of the body 12 and outer diameter of each disk 20, 22 are sized and configured such that each disk 20, 22 self-centers within the inlet chamber 18. One advantage of the orifice and swirl disks 20, 22 of the present invention is that because each disk is symmetrical (e.g., each disk is symmetrical about a plane perpendicular to its central axis), each disk is reversible, thereby alleviating the need for orientating a particular side up or down and further simplifying assembly. The plug 30 is then threadedly inserted into the inlet chamber 18 to press against the swirl disk 22. Although the plug 30 is threaded into the body 12, welding, pressing, staking, swaging or like methods may be used to insure that the plug 30, and thereby the disks 20, 22, are retained.

In operation, the nozzle 10 is mounted on a pipe or other structure such that liquid enters the internal bore 36 of the plug 30. The liquid exits the internal bore 36 via the set of exit orifices 38. Accordingly, the liquid travels into the annulus area 34 substantially perpendicularly to the axis of the nozzle 10. The annulus area 34 is in fluid communication

with the inlet 27 at the periphery of the swirl disk 22 so that the liquid within the annulus area 34 enters the inlet 27 of the swirl disk 22. As the liquid passes through the throat 26 of the inlet 27, the liquid enters the central aperture or swirl chamber 28 of the swirl disk 22 where a vortex is formed. Then, the liquid passes through the central aperture 24 of the orifice disk 20 and out of the outlet 16 of the body 12. Upon exiting the body 12, the turbulence of the swirling vortex forces the liquid to disintegrate into a fine mist.

Referring to Figure 8, an exploded view of a nozzle referred to generally by reference numeral 110 is shown. As will be appreciated by those of ordinary skill in the pertinent art, the nozzle 110 utilizes many of the same principles as the nozzle 10 described above. Accordingly, like reference numerals preceded by the numeral "1" are used to indicate like elements. The nozzle 110 has a body 112 for engaging a pipe or other structure (not shown) by a threaded end 114. Now also referring to Figures 9A and 9B, the body 112 defines an outlet 116 at the nose of the body 112 for discharging the liquid. An inlet chamber 118 is formed in the body 112 for receiving an orifice disk 120, a swirl disk 122, a plug 130 and filter 140. An intermediate portion 115 of the inlet chamber 118 defines threads for engaging the plug 130 which retains the disks 120, 122 in place. At the threaded end 114, the inlet chamber 118 has a relatively larger inner diameter for receiving the filter 140 in a press fit manner. Preferably, the filter 140 is a porous filter which causes minimal pressure drop.

Referring to Figures 10A and 10B, the orifice disk 120 has a central aperture 124 and is placed in the bottom of the inlet chamber 118 so that the central aperture 124 is adjacent to and axially aligned with the outlet 116 of the body 112. Referring to Figures 11A and 11B, the swirl disk 122 creates a vortex within a substantially central hollow or swirl chamber 128 defining a start radius "a". The swirl disk 122 is placed adjacent to the orifice disk 120 in the inlet chamber 118 so that the central hollow 128 is adjacent to and axially aligned with the central aperture 124. The swirl disk 122 also forms an inlet 127 in fluid communication with the central hollow 128 for channeling fluid thereto. The inlet 127 expands gradually from a throat 126 having a width "b" to an entry width "c" at the periphery of the swirl disk 122. Among other parameters, the throat ratio, which is the throat "b" divided by the start radius "a", controls the tightness of the vortex formed in the central hollow 128 and, thereby, affects the performance of the nozzle 110. U.S. Patent No. 3,771,728 details several additional parameters which may be varied to modify the shape of the vortex and is hereby expressly incorporated by reference as part of the present disclosure.

Referring to Figures 12A-C, the plug 130 has a threaded proximal portion 132 for engaging the inlet chamber 118 to retain the disks 120, 122. The distal end 133 of the plug 130 is relatively narrower in radius than the intermediate portion 132. As a result of the narrower distal end 133, when the plug 130 is inserted into the body 112, an annulus area 134 (see Figure 13E) is formed between the plug 130 and body 112. The annulus area 134 allows the fluid to pass into the inlet 127 of the swirl disk 122. The proximal portion 132 forms two flats 135 for allowing fluid to pass between the plug 130 and body 112 and into the annulus area 134. The flats 135 also are engageable by a tool, pick and place robot, or other device for assembling the nozzle 110.

Referring to Figures 13A-E, to assemble the nozzle 110, the orifice disk 120 is placed in the bottom of the inlet chamber 118. Similarly, the swirl disk 122 is placed directly adjacent to the orifice disk 120. In a preferred embodiment, the inner diameter of the inlet chamber 118 of the body 112 and outer diameter of each disk 120, 122 are sized and configured such that each disk 120, 122 self-centers within the inlet chamber 118. The plug 130 is then threadedly inserted into the inlet chamber 118 to press against the swirl disk 122 and thereby retain the orifice disk 120 against the outlet 116. Although the plug 130 is threaded into the body 112, welding, pressing, staking, swaging or like methods may be used to insure the plug 130 is fixed in place. Upon securing the plug 130, the filter 140 is press fit into the large diameter portion of the inlet chamber 118 at the threaded end 114.

In operation, the liquid enters the nozzle 110 via the filter 140 and passage formed between the flats 135 of the plug 130 and the body 112. The annulus area 134 collects the liquid passing beyond the flats 135. The annulus area 134 is in fluid communication with the inlet 127 at the periphery of the swirl disk 122 so that the liquid within the annulus area 134 enters the inlet 127. As the liquid passes through the inlet 127, the liquid enters the central aperture 128 of the swirl disk 122 where a vortex is formed. Then, the liquid passes through the central aperture 124 of the orifice disk 120 and exits from the outlet 116 of the body 112 where the kinetic energy of the liquid causes the liquid to disintegrate into a mist.

Table 1 below illustrates exemplary results of experiments conducted with nozzles embodying the present invention. During testing, it was determined that a tighter vortex within the swirl chamber yields comparatively better results in terms of droplet size and spray pattern. Also, it was determined that axial misalignment of the orifice disk with respect to the swirl disk skewed the spray pattern. Due to the symmetry of the disks 120, 122, neither disk 120, 122 has an impact upon performance when reversed. Thus, assembly of the nozzle

110 is simplified because neither disk 120, 122 has an “up” or a “down” side as the disks 120, 122 are placed in the nozzle 110.

With reference to Table 1, the "pressure" column indicates the pressure (in psi) of the fluid flowing into the nozzle. The "orifice diameter" is the diameter (in inches) of the spray orifice 24, 124. As shown, for example, in Figure 11B, the "swirl start radius" is the start radius "a" (in inches), and the “throat ratio” is the throat width “b” of the inlet 127 divided by the swirl start radius “a”. The “D32” column in Table 1 represents the Sauter Mean drop size. The “DV0.9” column represents a droplet diameter of the spray emitted by the nozzle such that 90% of the total volume (or mass) is composed of droplets with diameters less than the “DV0.9” diameter. The “mass” column represents in kilograms the amount of liquid collected during the collection time in minutes. The “flow” in gallons/minute is the mass divided by the collection time. Lastly, the “K-factor” column indicates an industry standard figure of merit that is proportional to flow, in which a higher number indicates a higher flow nozzle and a lower number indicates a lower flow nozzle for a given pressure.

pressure	orifice diameter	swirl start radius	throat ratio	D32	DV0.9	Mass	collection time	flow	K-factor*10^4
1000	0.006	0.03	0.85	25.2	44.6	0.111	2	0.014663	4.6368933
1000	0.013	0.02	0.85	17.8	31	0.1105	1	0.029194	9.2320127
1000	0.013	0.03	0.6	16.6	28.4	0.102	1	0.026948	8.5218579
1000	0.013	0.03	1.1	25.9	48.9	0.2205	2	0.029128	9.2111258
1000	0.013	0.04	0.85	33.6	49	0.1295	1	0.034214	10.819418
1000	0.02	0.03	0.85	40.6	62.8	0.2495	1	0.065918	20.845133
2000	0.006	0.02	0.85	22.6	38.8	0.1815	2	0.023976	5.3612462
2000	0.006	0.03	0.6	17.8	33.9	0.133	2	0.017569	3.9286267
2000	0.006	0.03	1.1	23.6	39.1	0.126	2	0.016645	3.7218569
2000	0.006	0.04	0.85	20.7	37.1	0.147	2	0.019419	4.3421664
2000	0.013	0.02	0.6	19.3	34.9	0.146	1	0.038573	8.6252556
2000	0.013	0.02	1.1	21.3	38.6	0.1835	1	0.048481	10.840647
2000	0.013	0.03	0.85	19.6	39.5	0.181	1	0.04782	10.692954
2000	0.013	0.03	0.85	17.4	31.1	0.183	1	0.048349	10.811108
2000	0.013	0.03	0.85	32.9	50.2	0.1595	1	0.04214	9.4227964
2000	0.013	0.04	0.6	23.8	44.9	0.156	1	0.041215	9.2160265
2000	0.013	0.04	1.1	32.5	50	0.1705	1	0.045046	10.072644
2000	0.02	0.02	0.85	29.7	49	0.2665	1	0.07041	15.744045
2000	0.02	0.03	0.6	16.9	28.8	0.267	1	0.070542	15.773584
2000	0.02	0.03	1.1	27.4	48.7	0.2815	1	0.074373	16.630202
2000	0.02	0.04	0.85	32.4	54.1	0.273	1	0.072127	16.128046
3000	0.006	0.03	0.85	23.6	40.1	0.194	2	0.025627	4.6789157
3000	0.013	0.02	0.85	27.9	46.7	0.213	1	0.056275	10.27432
3000	0.013	0.03	0.6	29	47.8	0.1985	1	0.052444	9.5748946
3000	0.013	0.03	1.1	27.6	44.6	0.2145	1	0.056671	10.346675
3000	0.013	0.04	0.85	22.5	38.2	0.2155	1	0.056935	10.394911
3000	0.02	0.03	0.85	31.6	48.9	0.2865	1	0.075694	13.819684
3000	0.013	0.02	0.85	27.5	59.4	0.1985	1	0.052444	9.5748946
3000	0.013	0.02	0.85	24.2	45.9	0.1884	1	0.049775	9.0877085
3000	0.013	0.02	0.85	28	47.5	0.2095	1	0.05535	10.105493
1000	0.013	0.02	0.85	17.8	34.2	0.113	1	0.029855	9.4408818
1000	0.013	0.02	0.85	17.4	31.1	0.115	1	0.030383	9.607977

TABLE 1

A significant advantage of the currently preferred embodiments of the present invention is that the nozzle can produce very small droplets without requiring very high pressures. For example, in turbine cooling applications, the nozzles of the present invention are capable of achieving acceptable droplet sizes at about 1,000 psi, whereas certain prior art nozzles may require pressures of 3,000 psi or higher to achieve comparable results. As a result, a system employing the nozzles of the present invention is capable of operating at lower pressures then permitted by certain prior art nozzles, thus permitting lower initial costs associated with pump skids as well as lower operating costs associated with the pumping systems. It is currently believed that one reason why the nozzles of the present invention are

capable of achieving such improved results is the ability to make the swirl chamber relatively small, and particularly the throat distance of the swirl chamber relatively small in comparison to prior art nozzles. In currently preferred embodiments of the present invention, the start radii are preferably within the range of about 0.02 inches through about 0.04 inches, and the throat ratios (i.e., the throat width divided by the swirl start radius) are within the range of about 0.6 through about 1.1. Yet another advantage of the present invention is that because the swirl chamber is formed in a disk having a sheet material substrate that may be machined by, for example, the above-described photochemical etching process, the swirl chamber can be made relatively small while nevertheless accurately maintaining relatively tight tolerances. As a result, the nozzles of the present invention are capable at a given pressure of more effectively and efficiently translating the pressurized fluid into smaller droplets than certain prior art nozzles.

Referring to Figures 14 and 15, an orifice disk 220 and a swirl disk 222 may have a plurality of paths through which a liquid may travel. As will be appreciated by those of ordinary skill in the pertinent art, the disks 220, 222 utilize many of the same principles as the disks 120, 122 described above. Accordingly, like reference numerals preceded by the numeral "2", or preceded by the numeral "2" instead of the numeral "1", are used to indicate like elements. The orifice disk 220 has two spray apertures 224. The orifice disk is received within a retaining body (not shown) in the same manner as the orifice disks described above such that each spray aperture 224 is axially aligned with and adjacent to a respective outlet formed in the retaining body to discharge the nozzle spray therethrough. The swirl disk 222 defines a pair of hollows 228 that form swirl chambers for creating vortexes of liquid therein. The swirl disk 222 is placed adjacent to the orifice disk 220 within the retaining body so that the hollows 228 are located adjacent to and axially aligned with the respective spray apertures 224. The swirl disk 222 also defines a pair of inlets 227, wherein each inlet is connected in fluid communication with the respective hollow 228 for channeling fluid thereto. In the illustrated embodiment, each of the disks 220, 222 forms a notch 235 for receiving a protrusion on the retaining body (not shown) such that receipt of the protrusion(s) within the notch(es) aligns the spray apertures 224 of the orifice disk with the hollows 228 of the swirl disk and the outlets of the retaining body (not shown).

As may be recognized by those of ordinary skill in the pertinent art based on the teachings herein, the orifice disks may define any desired number of spray orifices, the swirl disks may define any desired number of swirl chambers, and the orifices and swirl chambers

may be located as desired within the respective disks. In addition, the retaining body may define a common fluid inlet for all swirl chambers and spray orifices, or may define separate fluid inlets for separate swirl chambers and spray orifices, or for separate groups of swirl chambers and spray orifices. In addition, the retaining body may define a plurality of outlet apertures, wherein each outlet aperture is aligned with a respective spray orifice of the orifice disk, or may define a lesser number of outlet apertures than spray orifices such that all spray orifices discharge through a common outlet aperture, or a group of spray orifices discharge through a common outlet aperture. Also, the retaining body may define a manifold having formed therein a plurality of recesses, wherein each recess is adapted to receive a respective orifice disk and swirl disk, and the retaining body may define a common plug or other retaining device, or may define a plurality of plugs or other retaining devices, for fixedly securing the orifice disks and swirl disks to the manifold. In addition, the plug or other retaining device may define a common fluid inlet for all swirl chambers, or may define separate fluid inlets for separate swirl chambers or groups of swirl chambers.

Referring to Figures 16-17E, another nozzle in accordance with the subject invention is referred to generally by reference numeral 310. As will be appreciated by those of ordinary skill in the pertinent art, the nozzle 310 utilizes many of the same principles as the nozzles described above. Accordingly, like reference numerals preceded by the numeral “3”, or preceded by the numeral "3" instead of the numerals "2" or "1", are used to indicate like elements. In a currently preferred embodiment, the body 312 of the nozzle 310 is manufactured by metal injection molding (“MIM”). Metal injection molding starts with combining a metal powder with a binder. The metal powder/binder mixture is injected into a mold cavity and sintered within the mold cavity to form the finished body 312. One advantage of using metal injection molding is that the body 312 requires no polishing, assembly and/or alignment of, for example, a swirl unit or orifice plate, because the swirl chamber(s) and spray orifice(s) are formed integral with the body.

The body 312 includes a threaded end 314 for engaging a pipe or other structure (not shown). The body 312 also defines an inlet chamber 318 and a threaded portion 319 for threadedly receiving within the inlet chamber a plug (not shown). The plug 318 may be the same as either of the plugs 30, 130 described above, or may define a different configuration. In either case, the plug need not perform the function of retaining a swirl disk and orifice disk within the body, but rather need only function to define a fluid flow path between the fluid inlet and the swirl chamber. The end wall 321 of the body defines a spray aperture 324

extending therethrough, a spray outlet 316 formed on one side of the spray orifice, and a recessed hollow 328 formed on the opposite side of the spray orifice and defining a swirl chamber connected in fluid communication with the spray orifice. A recessed inlet 327 is also formed on the interior side of the end wall 321 of the body and defines a inlet for channeling fluid into the swirl chamber. As can be seen, the swirl chamber 328 and swirl inlet 327 are virtually identical to the swirl chamber and inlet formed in the swirl disk 122 as shown in Figure 11A.

Assembling the nozzle 310 is a relatively simple procedure requiring: 1) insertion of the plug and filter, if required (not shown) into the inlet chamber 318; and 2) attachment of the threaded end 314 of the body 312 to a pipe. In operation, the fluid flows through the plug, into the annulus formed between the inner end of the plug and the body, and into the inlet 327 of the swirl chamber. In the swirl chamber 328, the swirling fluid forms a vortex and is, in turn, discharged in a spray through the spray orifice 316 and out of the nozzle.

While the invention has been described with respect to preferred embodiments, those skilled in the art will readily appreciate that various changes and/or modifications can be made to the invention without departing from the spirit or scope of the invention. For example, the swirl chamber may be an integral piece of the end of the plug. A plurality of nozzles embodying the present invention may be mounted into a manifold, such as by threadedly mounting each nozzle to the manifold, to create a plurality of nozzles in close proximity to each other that utilize the same fluid source. Alternatively, each nozzle may utilize a different fluid inlet, or respective groups of nozzles may utilize common inlets. In addition, the nozzles of the present invention, including the swirl disks and/or orifice disks of such nozzles, may be made of any of numerous different materials that are currently or later become known for performing the functions of the nozzles, or the respective components of the nozzles. In addition, the components of the nozzles, including the bodies, swirl disks, orifice disks, and plugs, may take any of numerous different shapes and/or configurations that might be desired or otherwise required for a particular application. Further, the swirl chambers and inlets to the swirl chambers may take any of numerous different configurations that are currently or later become known. In yet another alternative embodiment of the present invention, the spray orifice may be formed in the end wall of the body as shown in Figure 16, and the swirl chamber may be formed by a separate swirl disk, such as the swirl disk 22, 122, or 222. In another embodiment of the present invention, the swirl disk and/or orifice disk are surface treated with one or more wear-resistant coatings, such as a diamond coating or Titanium

Nitride, in order to improve wear life. Accordingly, this detailed description of preferred embodiments is to be taken in an illustrative as opposed to a limiting sense.